

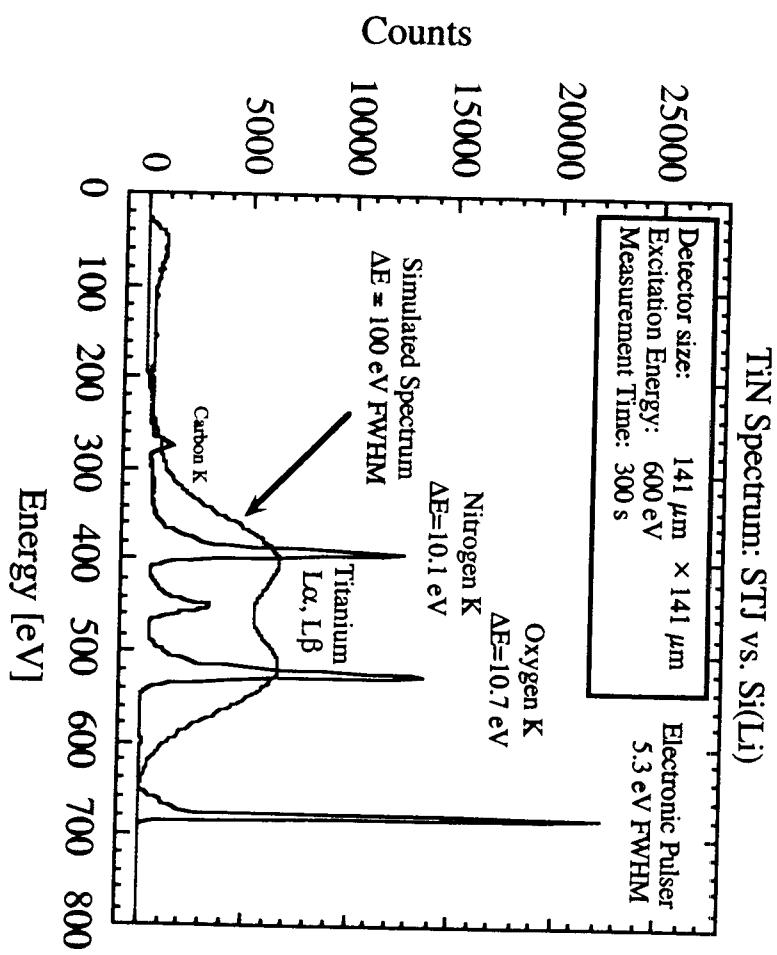
# High Resolution Superconducting Tunnel Junction Detectors

Stephan Friedrich, M. Frank, ..., S. E. Labov

LLNL/LBL

# Motivation

- High energy resolution
- High count rate
- Timing



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# Semiconducting and Cryodetectors



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Si(Li) or Ge detectors	Tunnel junctions	Microcalorimeters
Low resolution (60 - 100 eV from 0.5 to 6 keV)	High resolution (2-12 eV from 0.1 to 6 keV)	Higher resolution (2-5 eV from 0.5 to 6 keV)
Fast	Moderately fast (10,000 counts/s)	Slow (500 counts/s)
Large Area few mm <sup>2</sup> / pixel	Smaller (200μm x 200μm/ pixel)	Small (≈ 400μm x 400μm/ pixel)
Moderately low temperature (77 K)	Low temperature (below 0.5 K)	Lower temperature (0.1 K, regulated)
High efficiency	High efficiency up to 1 keV (can be improved)	High efficiency up to 6 keV

# Who is who in the Cryodetector World?

NIST (TES)      Yale (STJ)

J. Martinis

D. Prober

ESA (STJ)      SRON (TES)

T. Peacock

P. de Korte

LLNL (STJ, TES)

S. Labov, M. Frank

S. Friedrich (LBNL)

TUMunich (STJ)

F.v. Freilitsch

Munich:

CSP Inc. (TES)

Stanford (TES)

B. Cabrera

NASA/Wisconsin

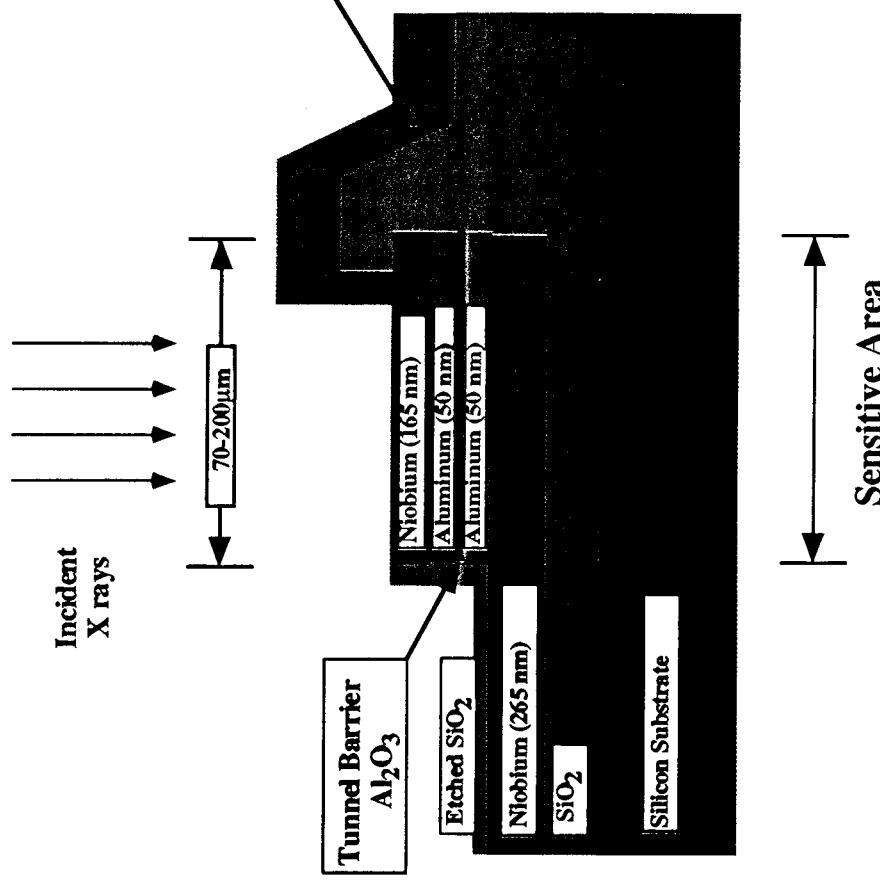
H. Moseley

D. McCammon

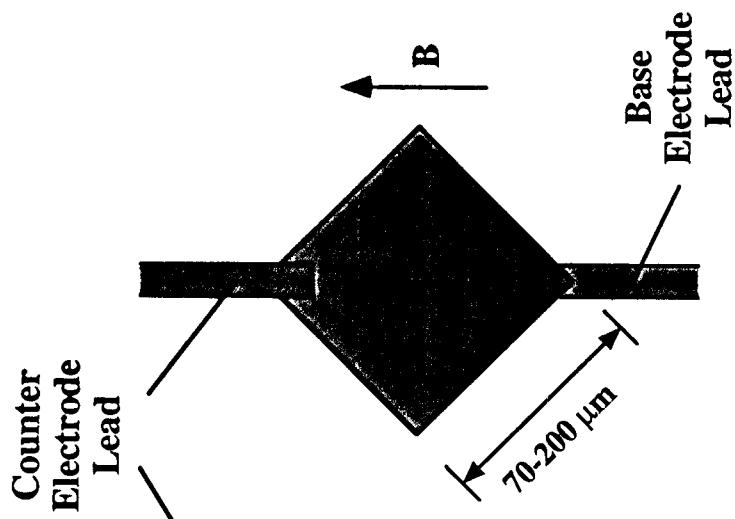
# Schematic of the STJ Detector

(STJ = Superconducting Tunnel Junction)

a) Cross Section



b) Top View



Fabricated at Conductus, Inc.

# STJ Detector Operating Principle



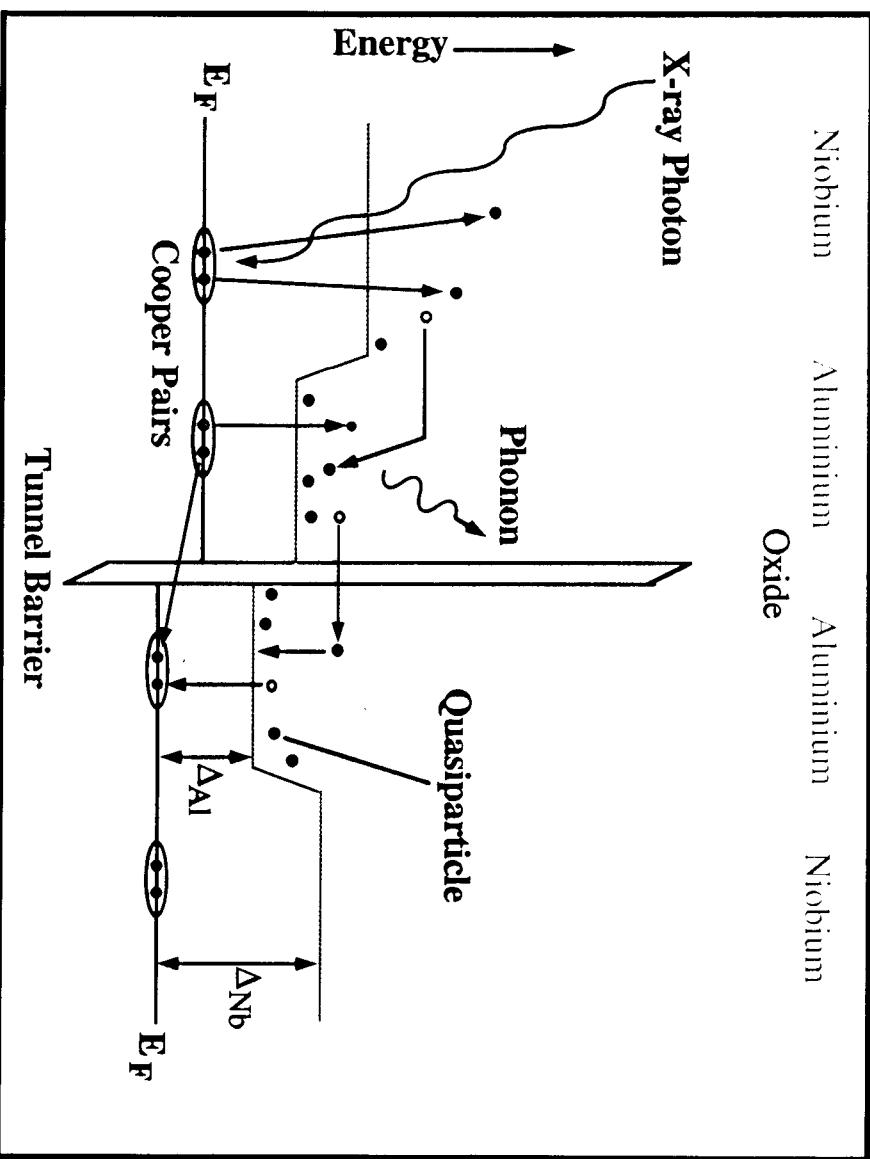
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- An X ray is absorbed in the superconductor, breaking  $\sim 10^6$  Cooper pairs into quasiparticles

- The number of quasiparticles N is proportional to the energy of the absorbed X ray

- Quasiparticles are trapped in a lower-gap region near the tunnel barrier

- Number of quasiparticles is measured by measuring the amplitude of a current pulse caused by the tunneling of the quasiparticles through the tunnel barrier

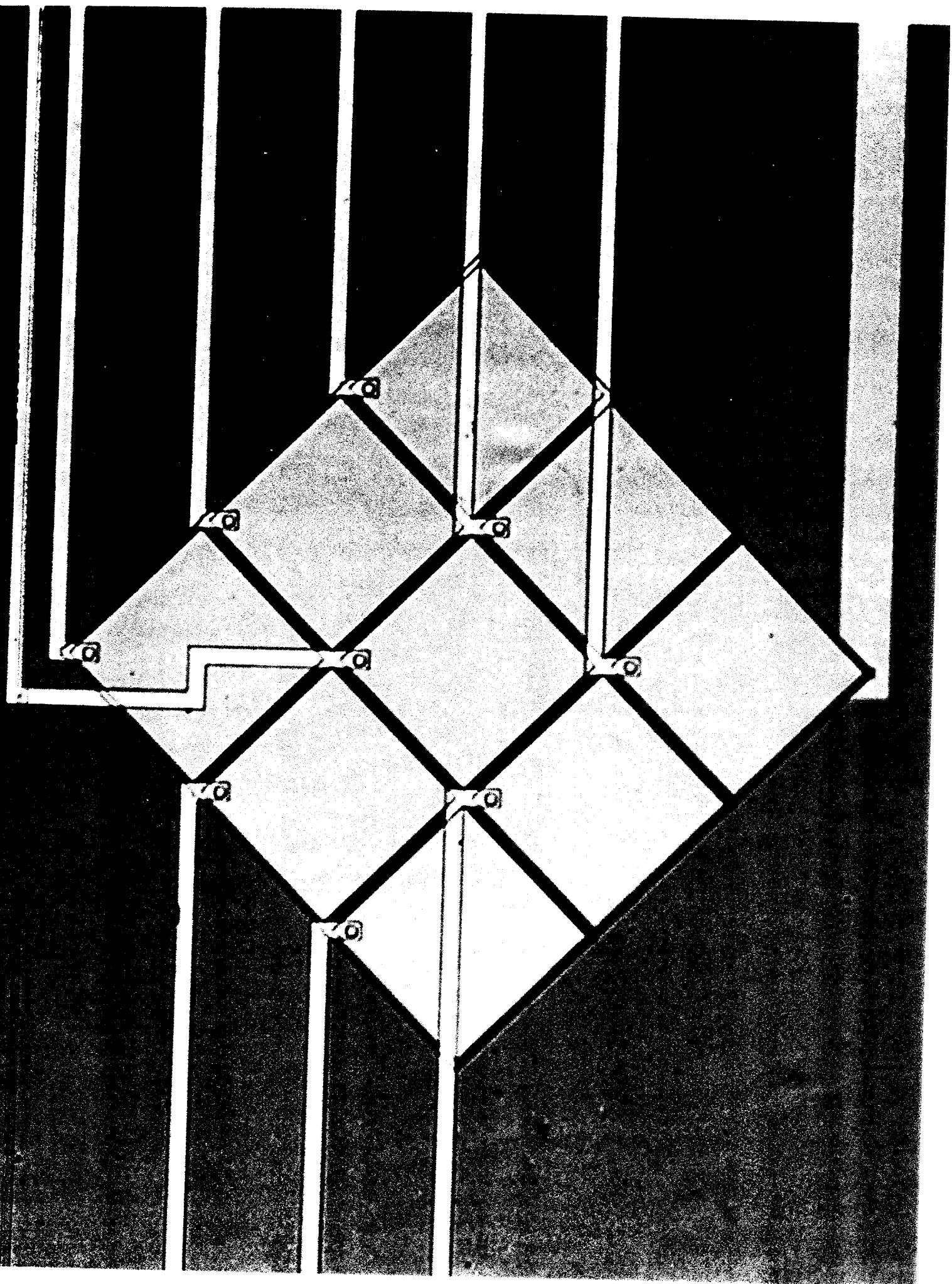


- Statistical Limit of Resolution:

$$\Delta E (\text{FWHM}) = 2.35\epsilon(\text{FN})^{1/2}$$

Nb:  $\epsilon \sim 2.6 \text{ meV}$ , F  $\sim 0.2$   
 $\sim 5 \text{ eV}$  for a 6 keV X-ray

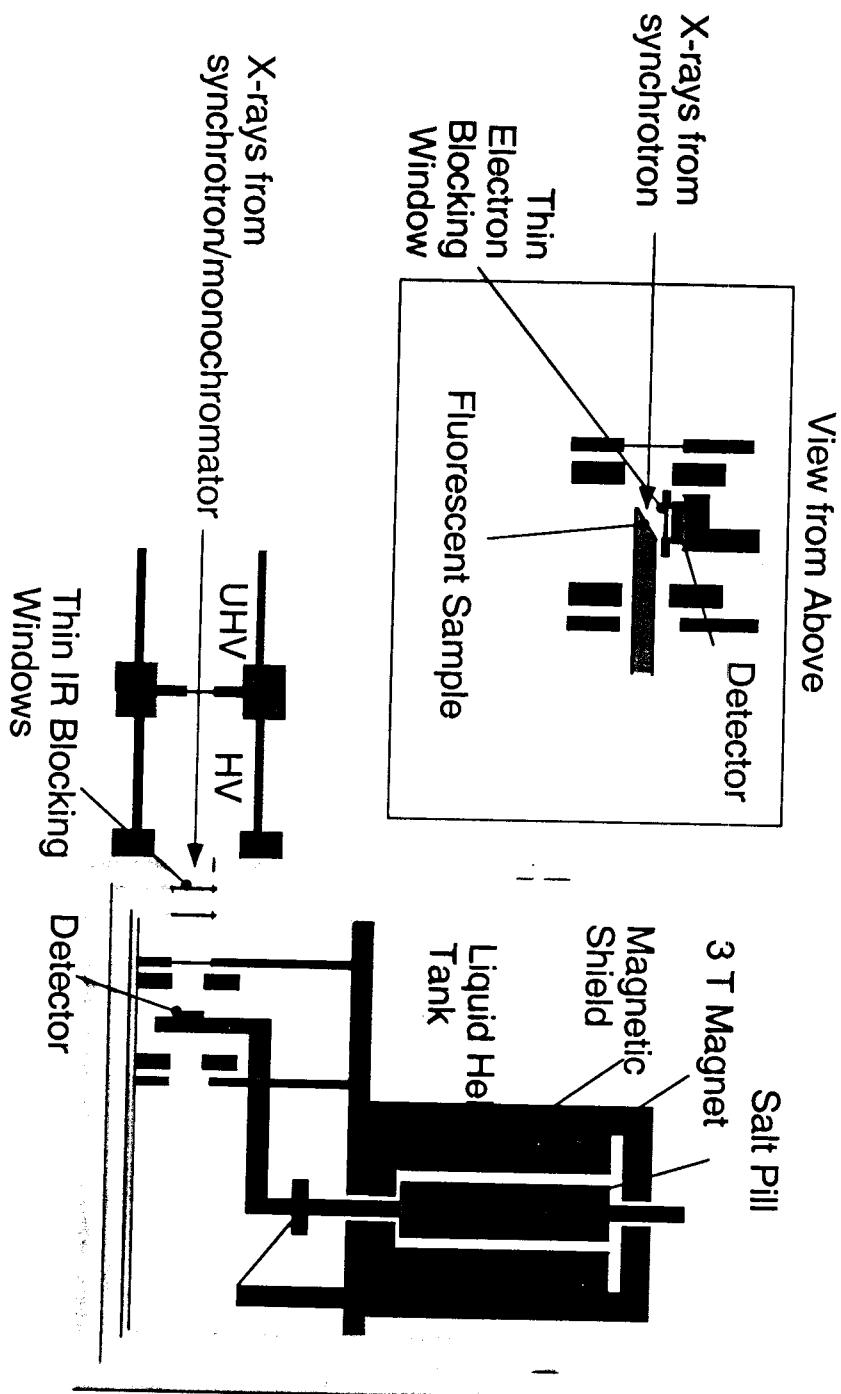
Signal = Current Pulse



# Experimental Setup Schematic



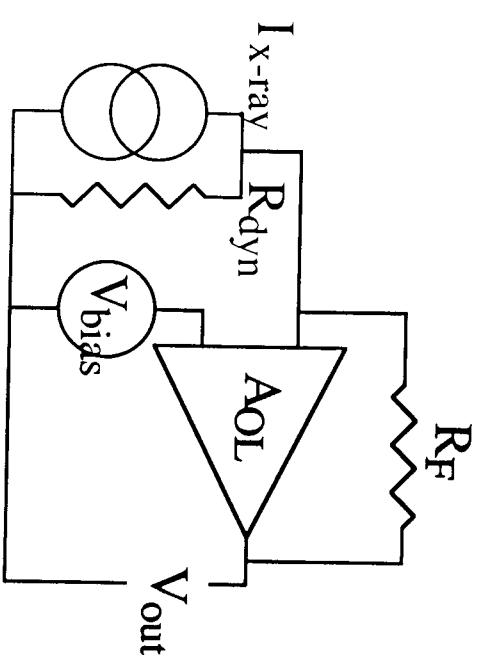
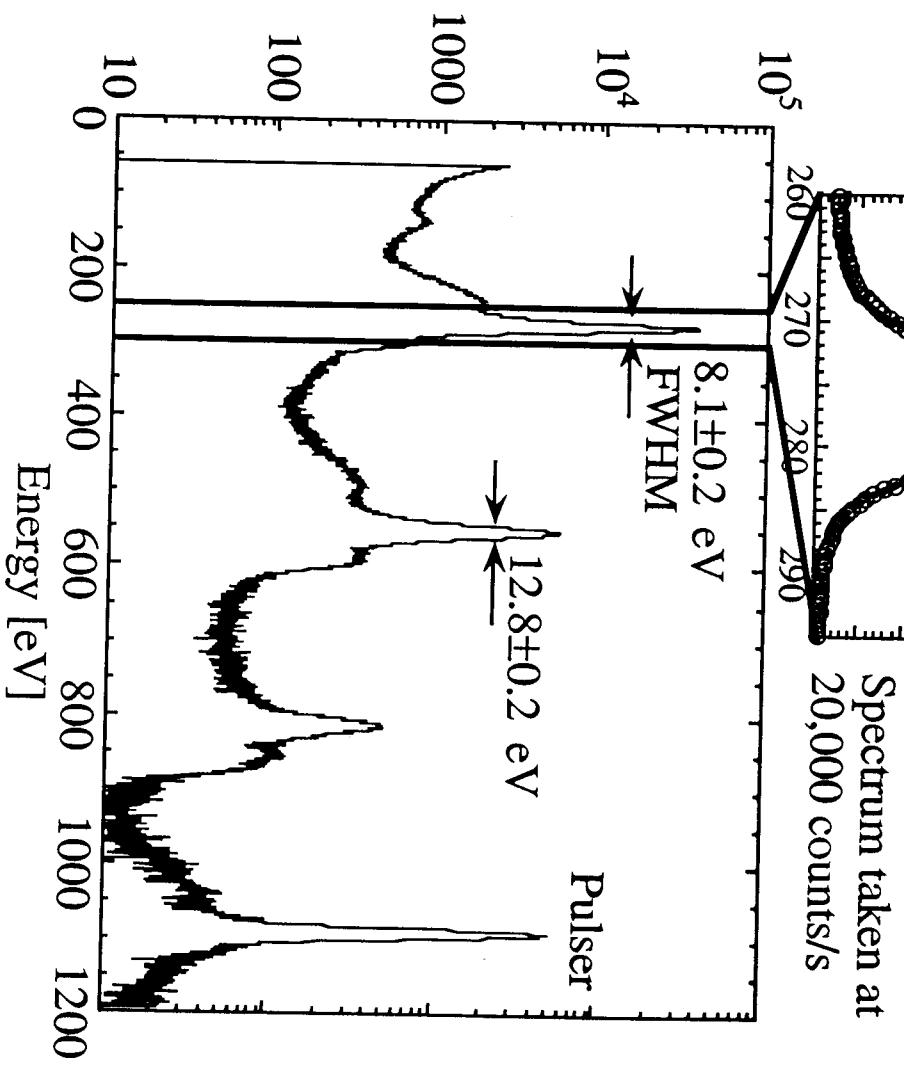
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# High Resolution at High Count Rate



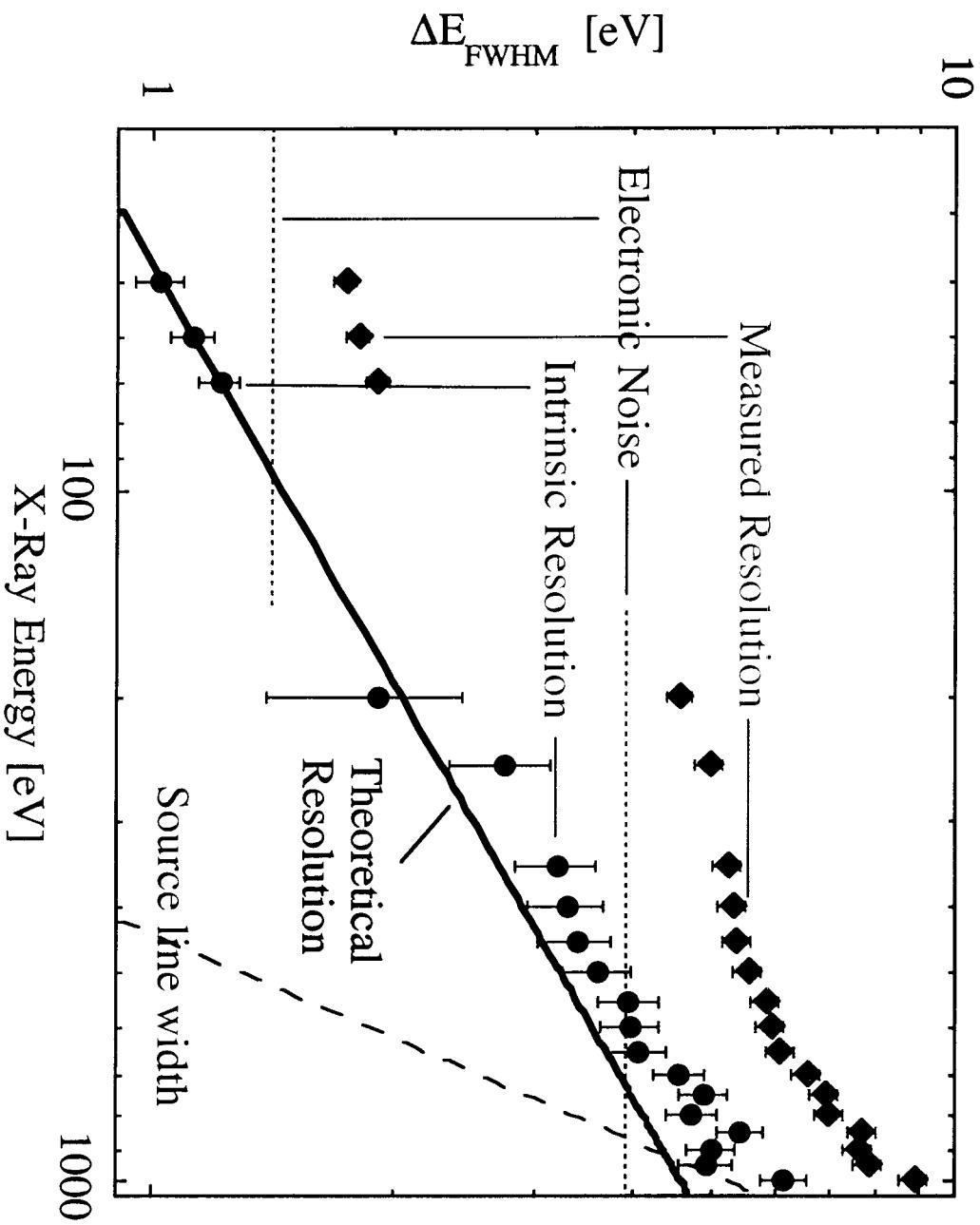
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Current pre-amp with dc V bias

2SK146 FET/A250: 0.23 pA/ $\sqrt{\text{Hz}}$

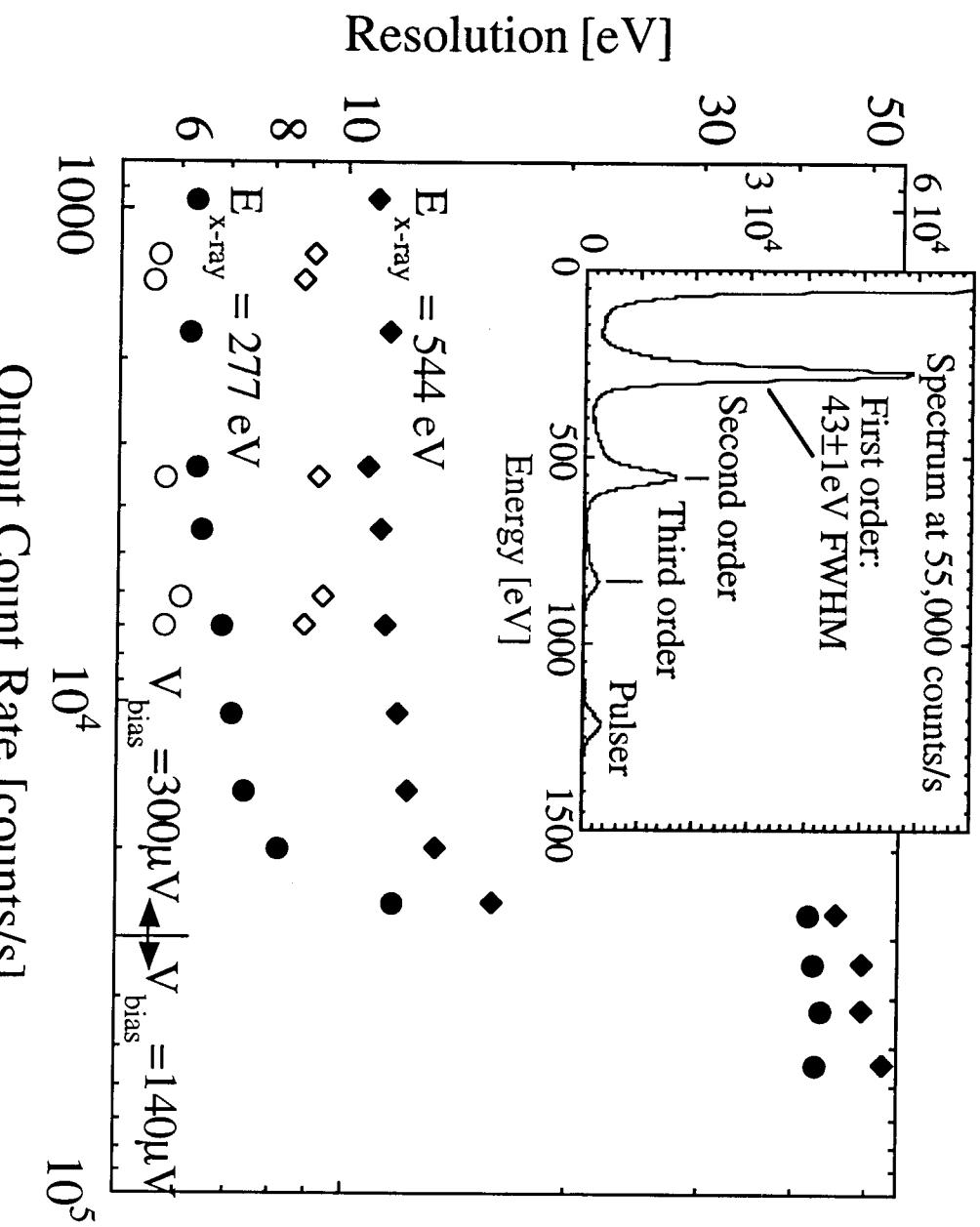
# Resolution vs. Energy



Intrinsic resolution approaches limit set by quasiparticle counting statistics.

# Energy Resolution vs. Count Rate

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- No pile-up rejection was used: 8.2 eV FWHM at 277 eV at 20,000 counts/s
- Above 30,000 counts/s, bias is unstable between Fiske modes.

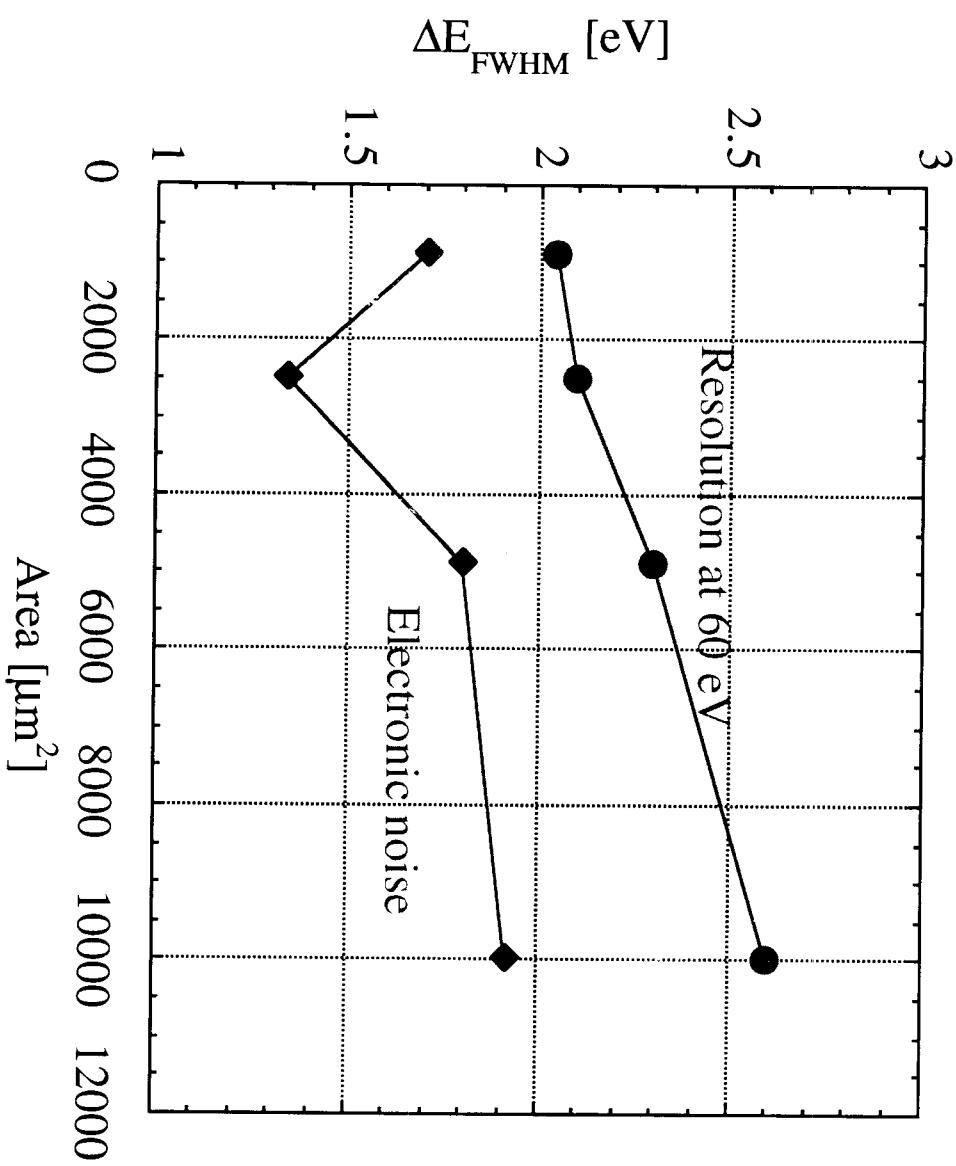
# Resolution vs. Area



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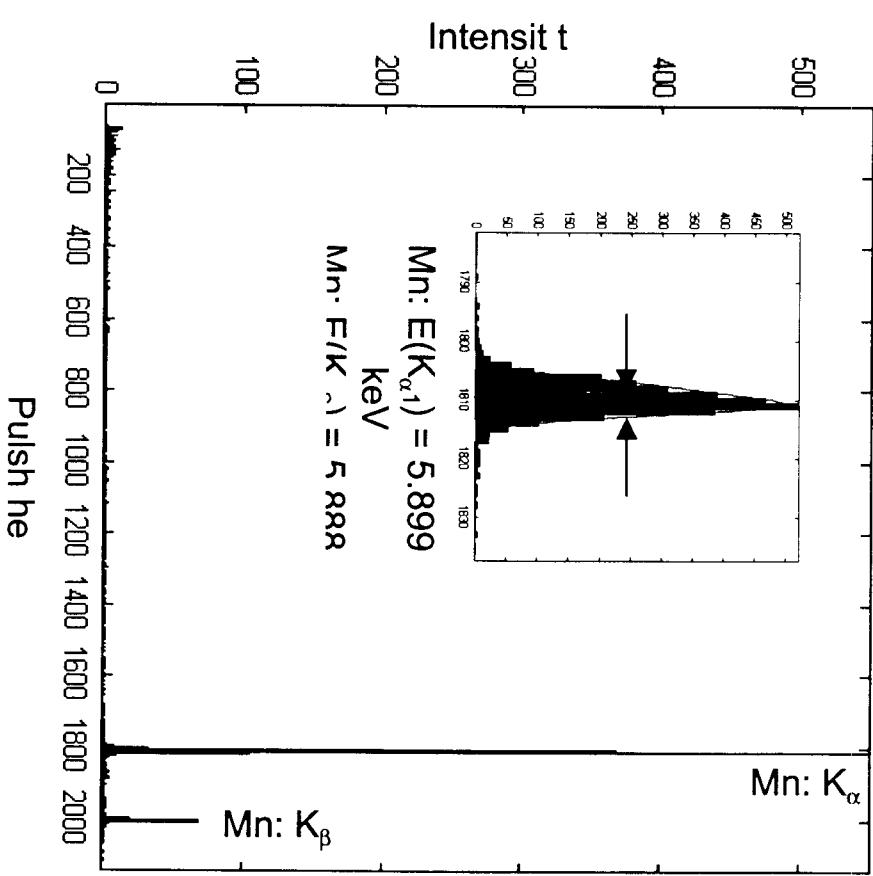
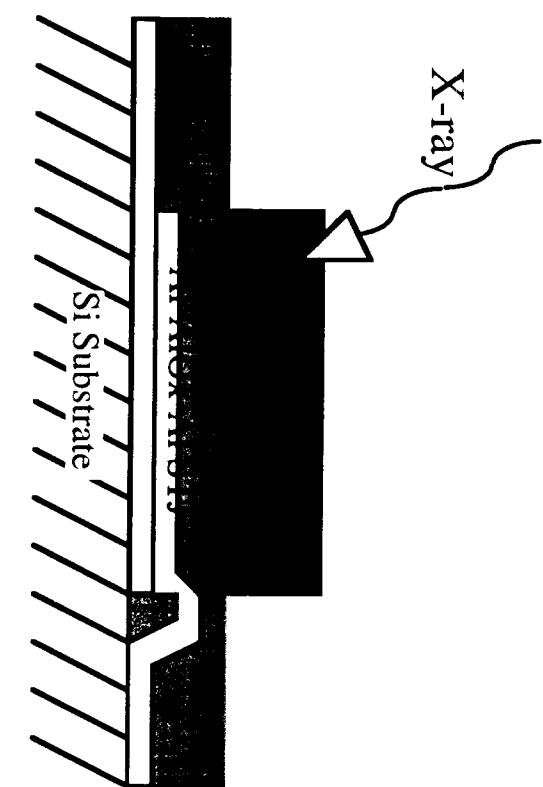
Area-dependent effects:

- Capacitance
- Spatial variations
- Perimeter-area ratio
- Fiske modes



# Separate Pb Absorber

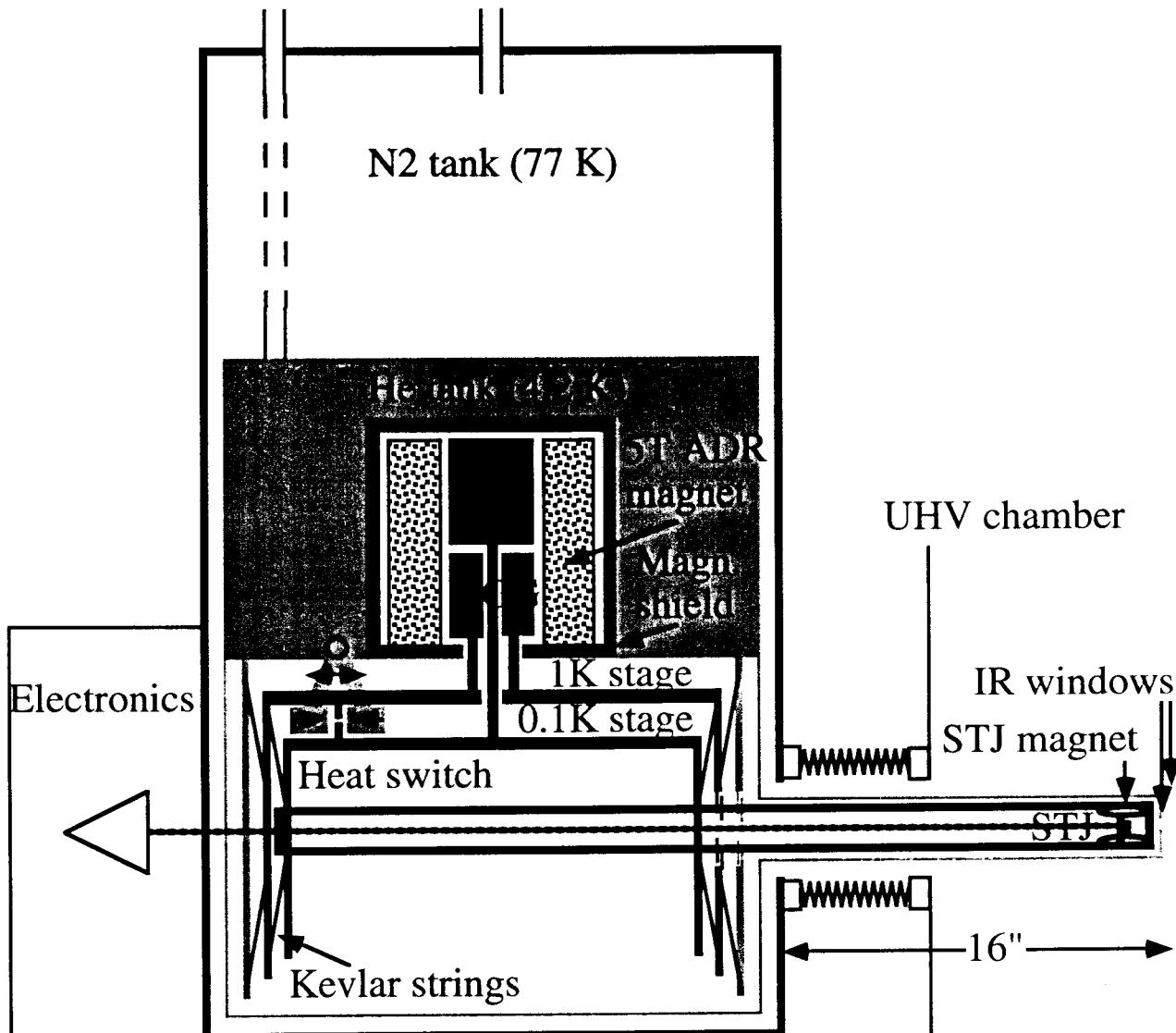
Angloher et al.,(2000), Technical University Munich



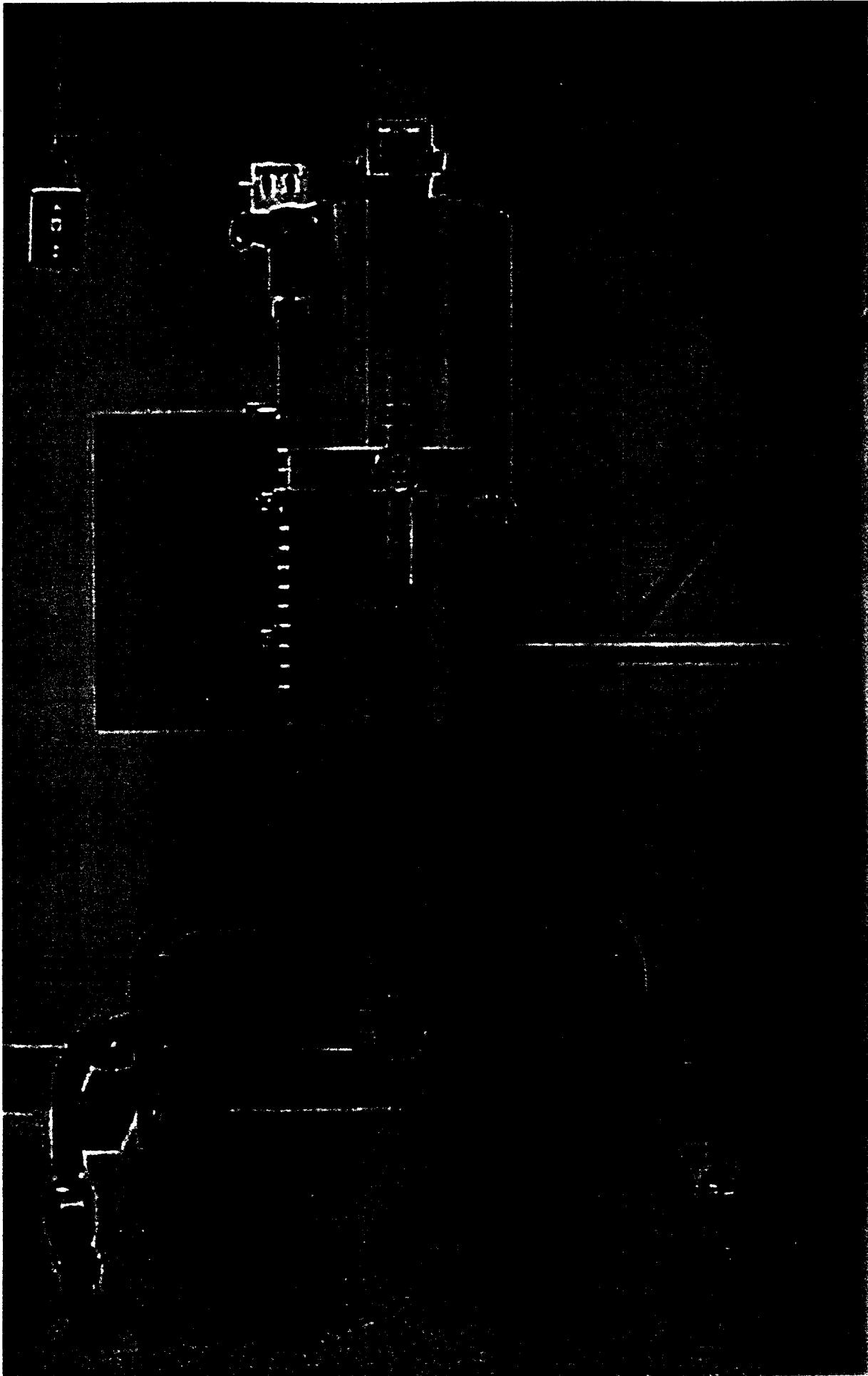
High resolution without line splitting at higher energy

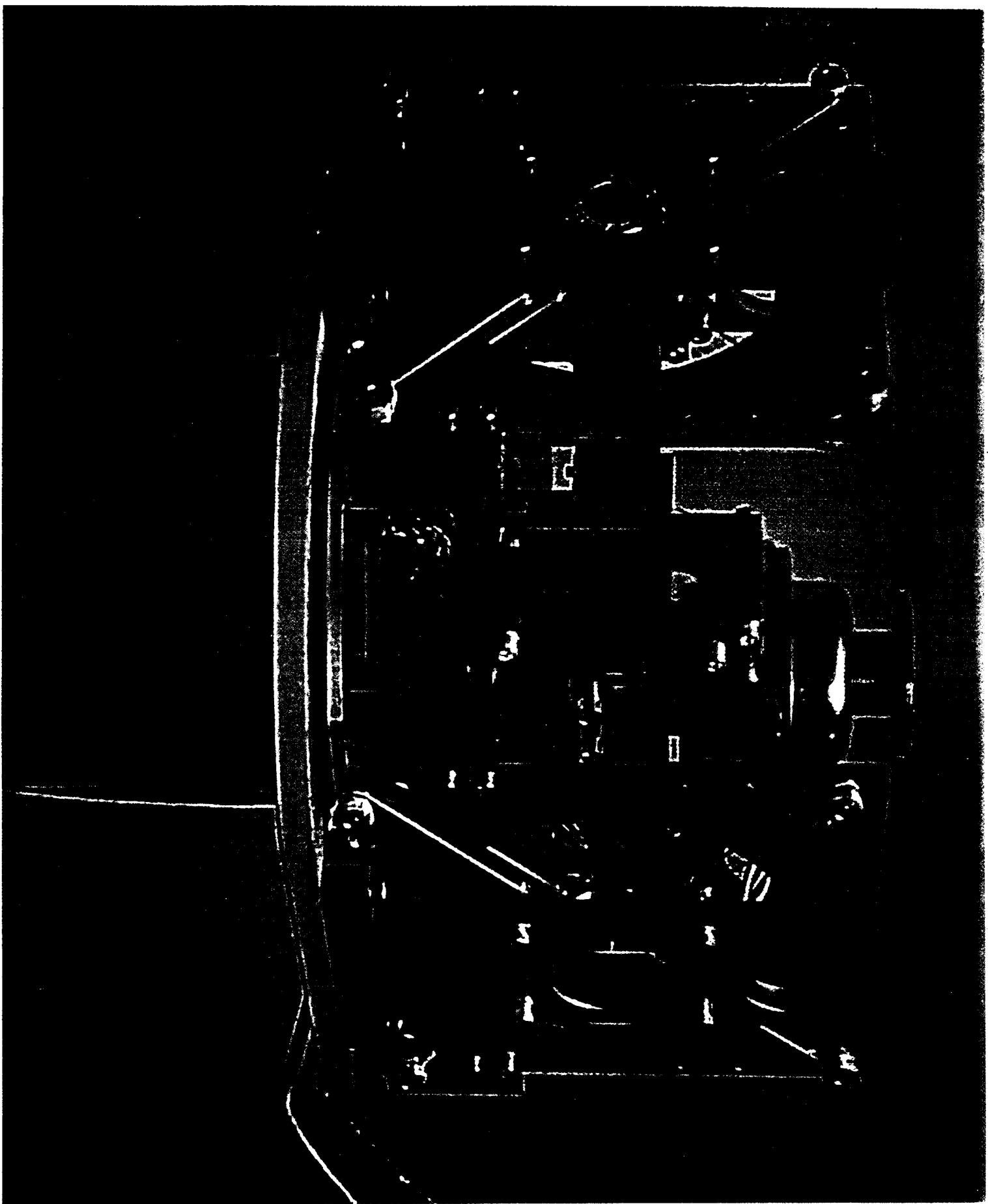
# ADR Cryodetector System

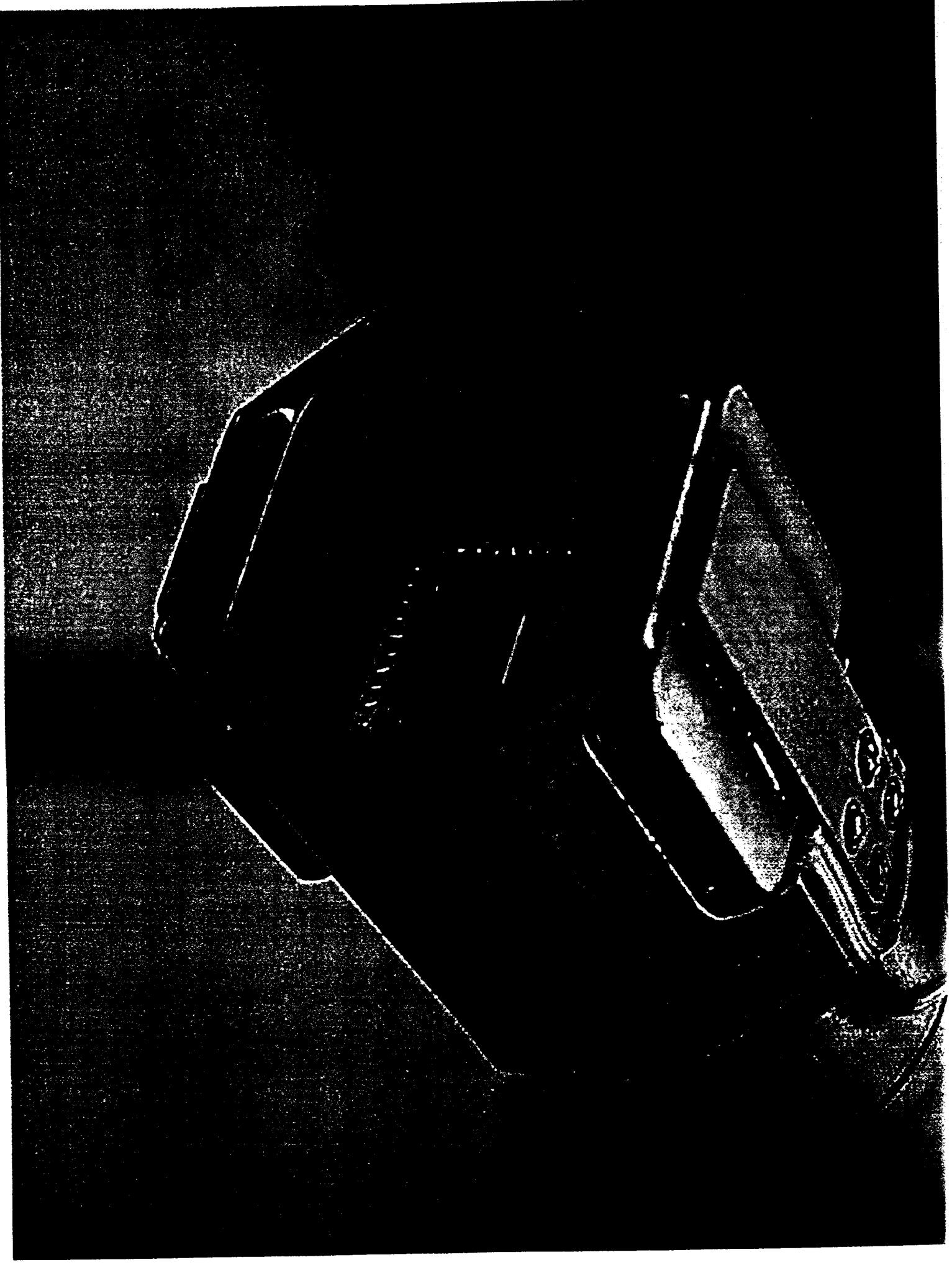
(ADR = Adiabatic Demagnetization Refrigerator)



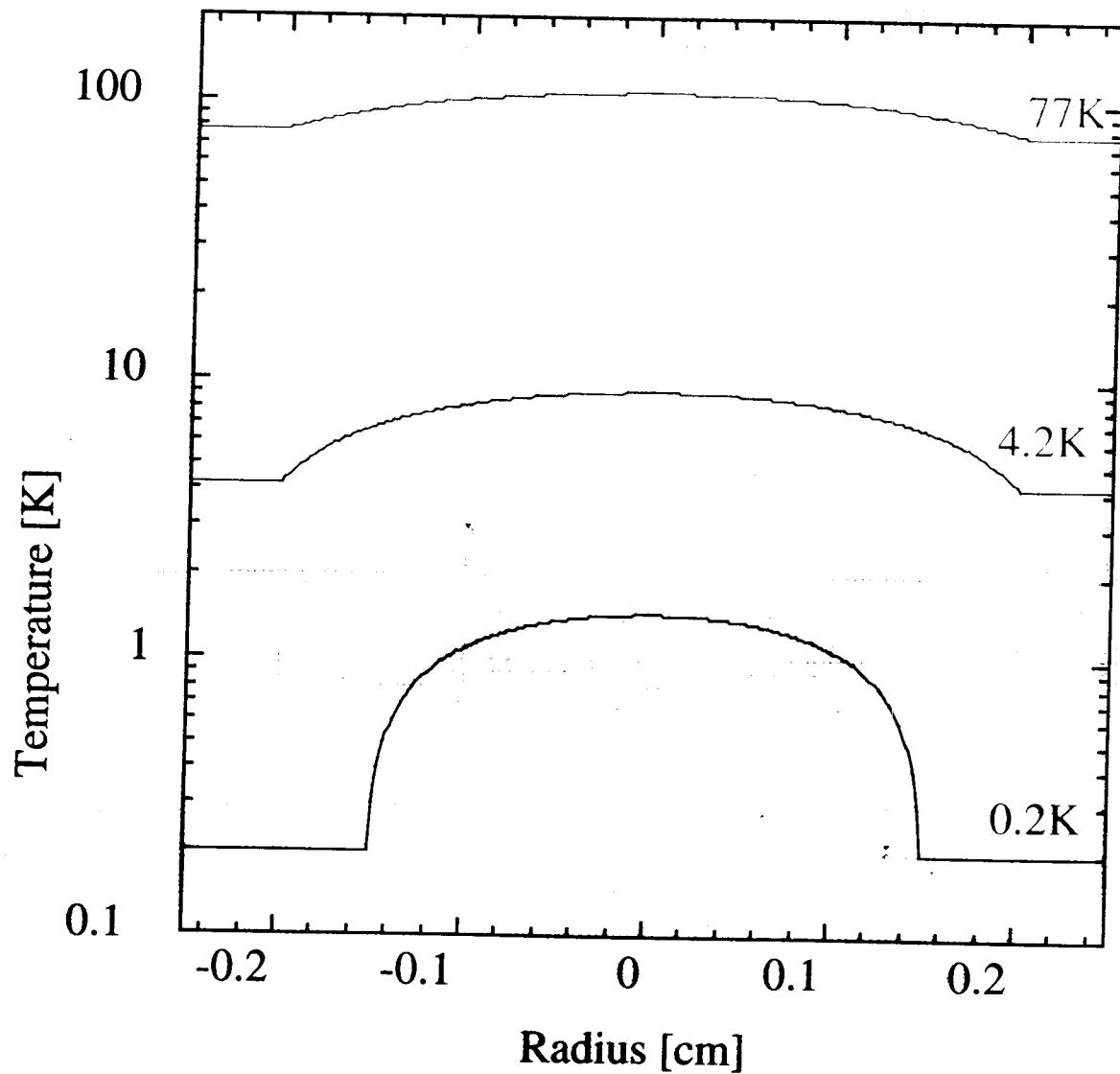
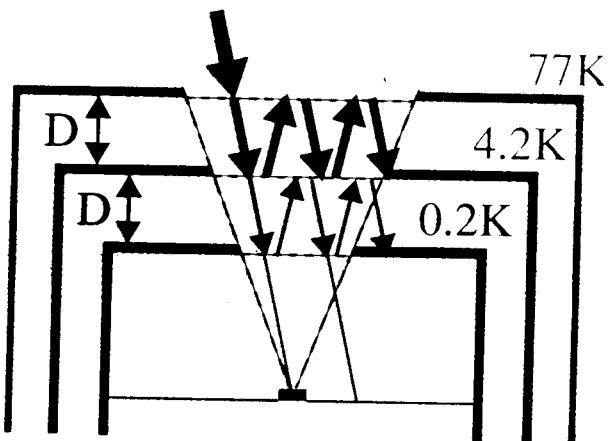
- 85 mK base T
- 20 hours hold time below 400 mK
- UHV pressure in  $10^{-9}$  range

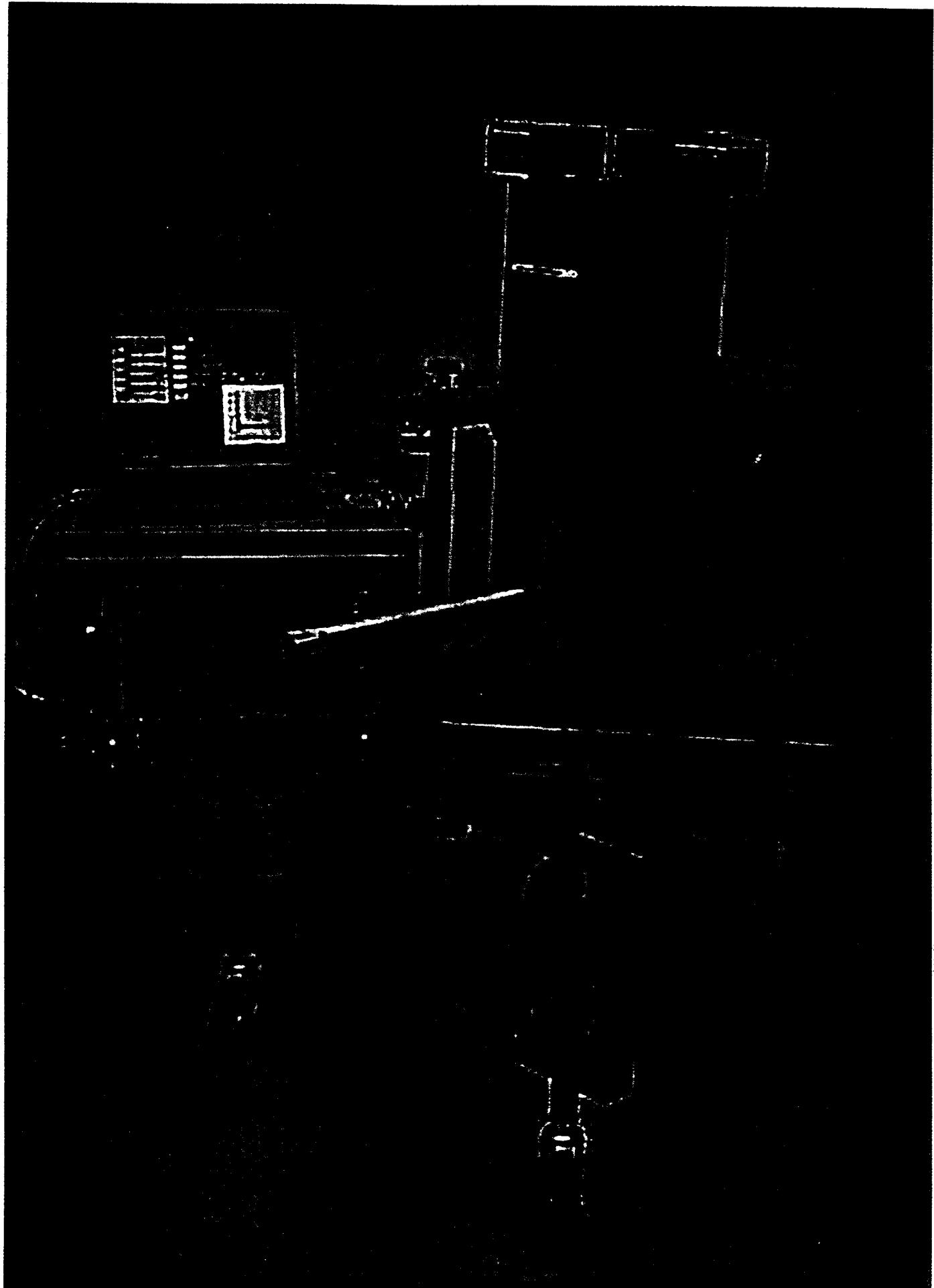


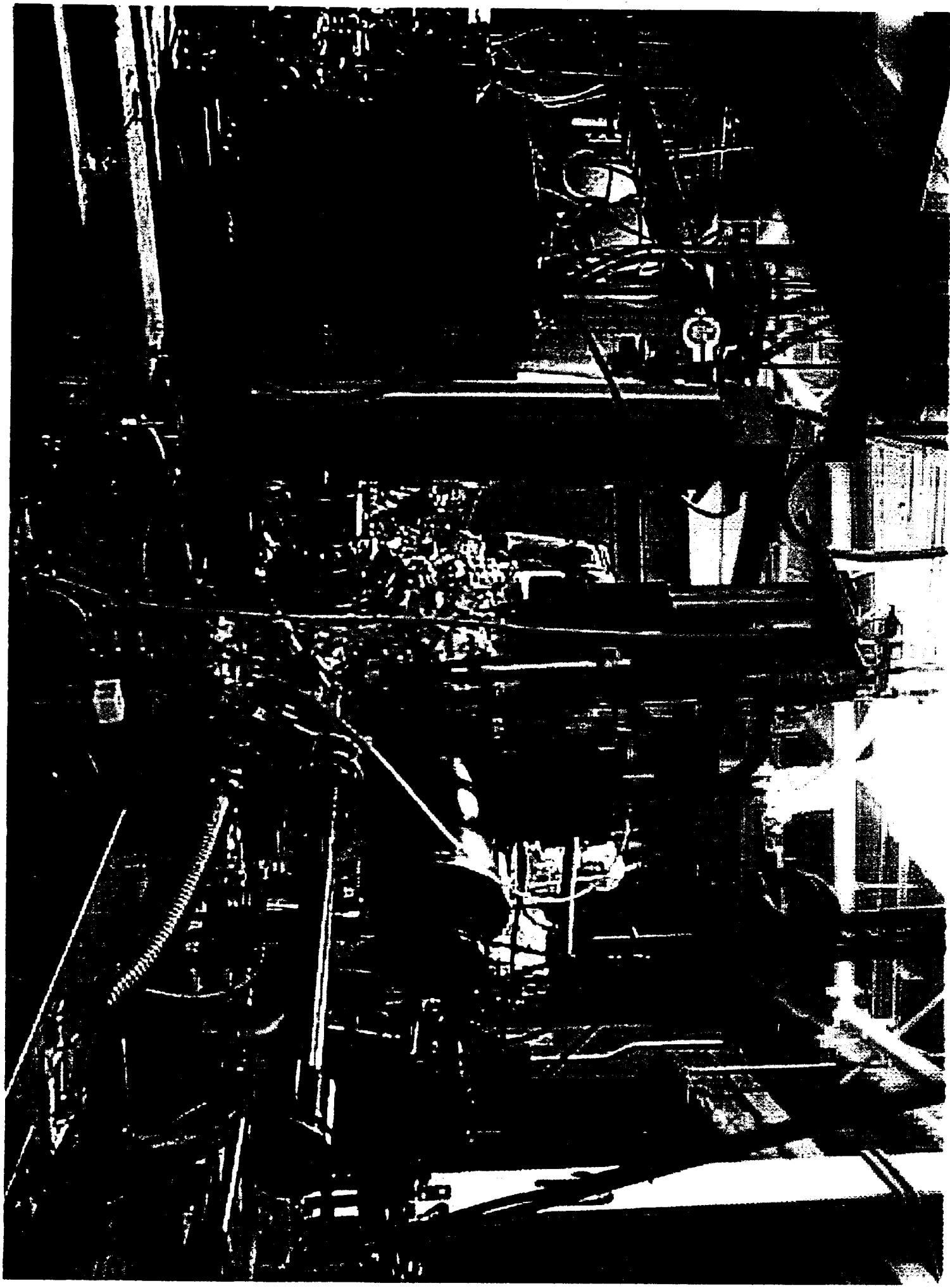


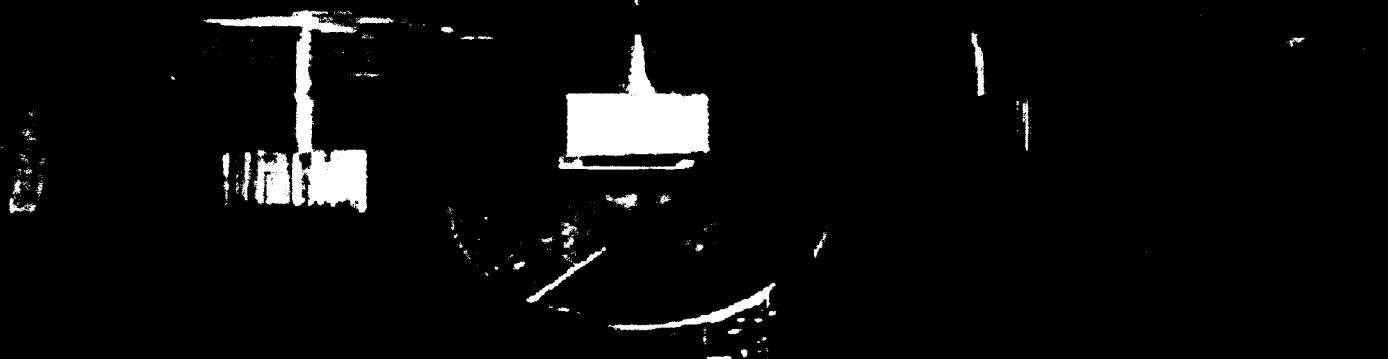


# Temperature of IR Windows







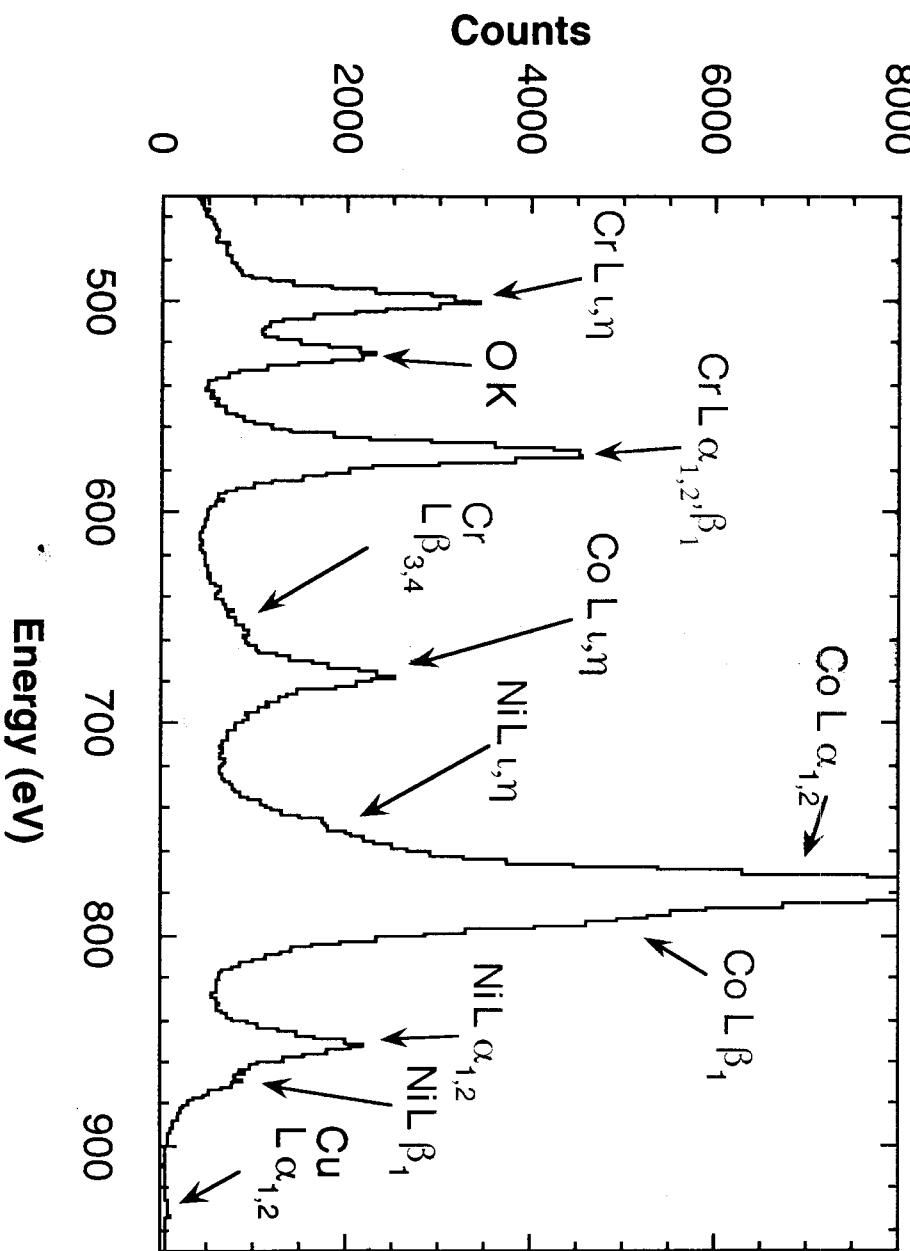


# Fluorescence Spectra: Hard disk



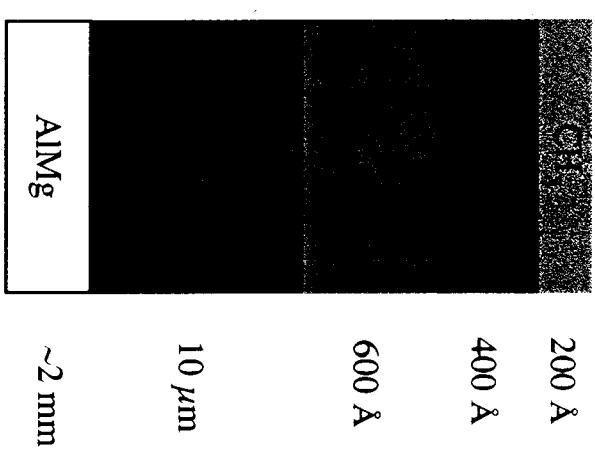
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**SR-XRF Spectrum from IBM Magnetic Storage Disk Sample  
Measured with STJ Detector (count rate 1.2 kHz)**



Disk Cross Section

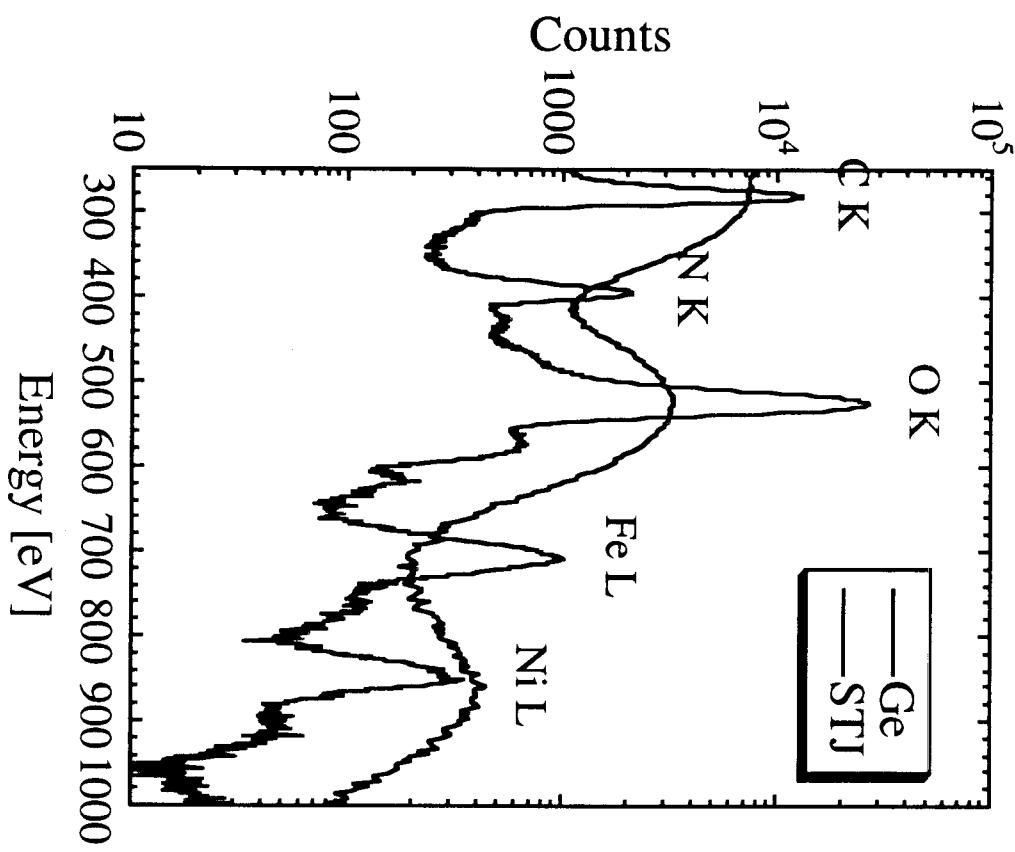
Resolution	12-14 eV
(FWHM)	
Electronic Noise	7 eV (FWHM)



AIMg

~2 mm

# Metalloprotein Spectroscopy

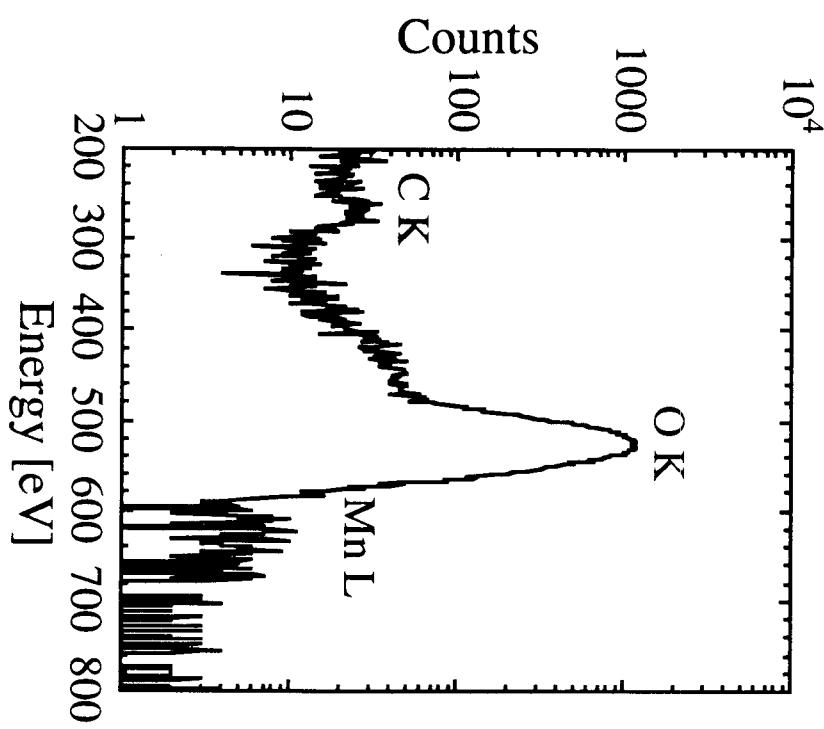


Dilute samples: 500 ppm Ni

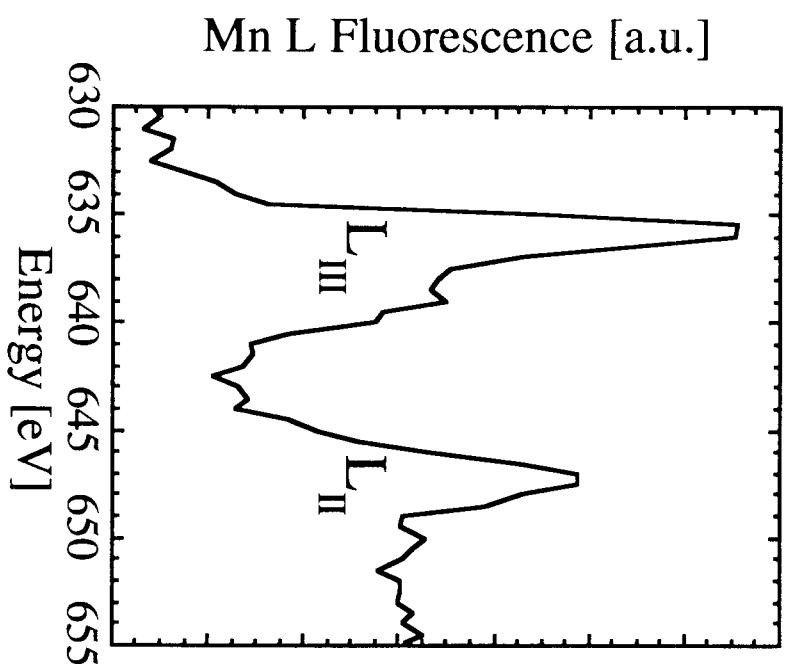


# 3100 ppm Mn in MgO

Emission Spectrum



Absorption Spectrum

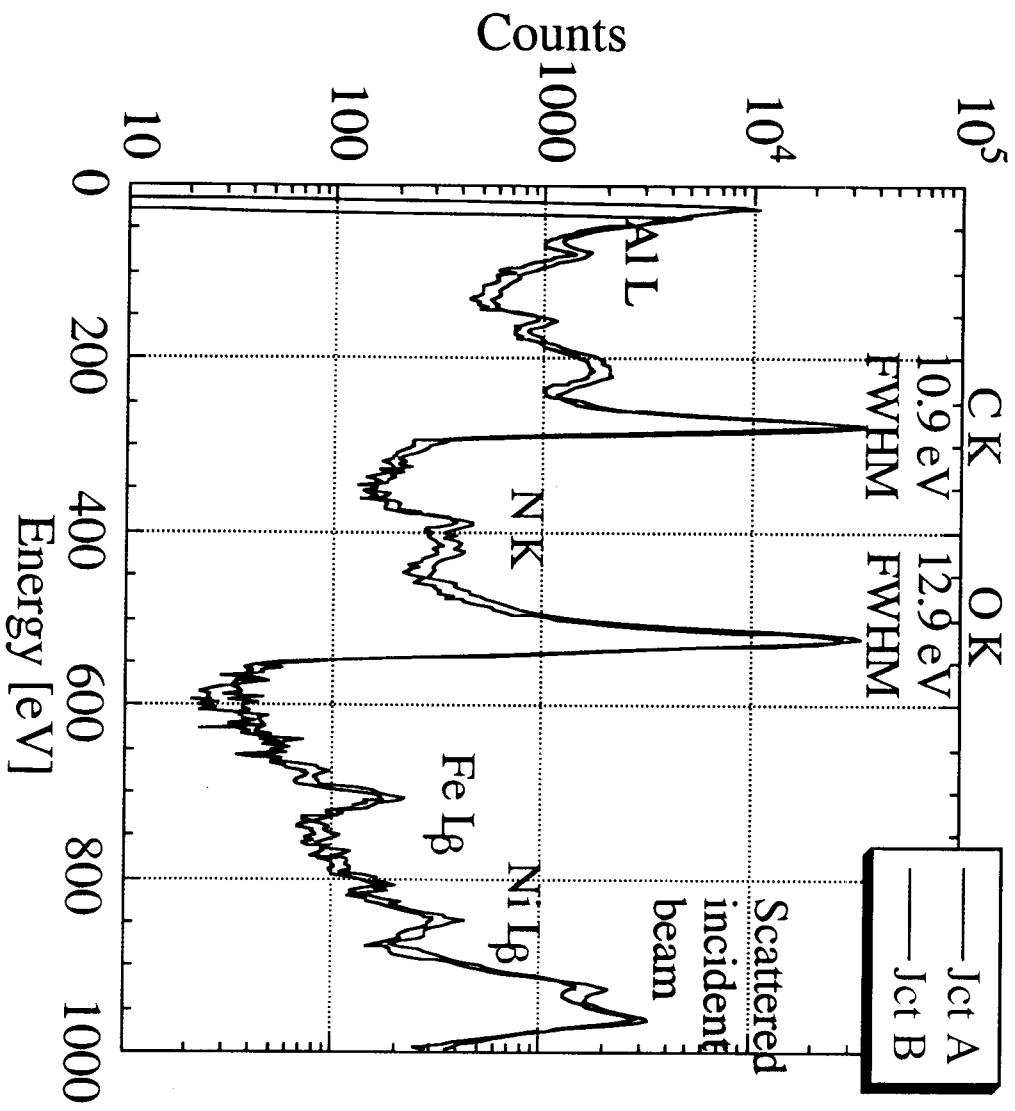


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# Two Junction Array



Fluorescence spectrum  
of metalloprotein  
Hydrogenase (500 ppm Ni)

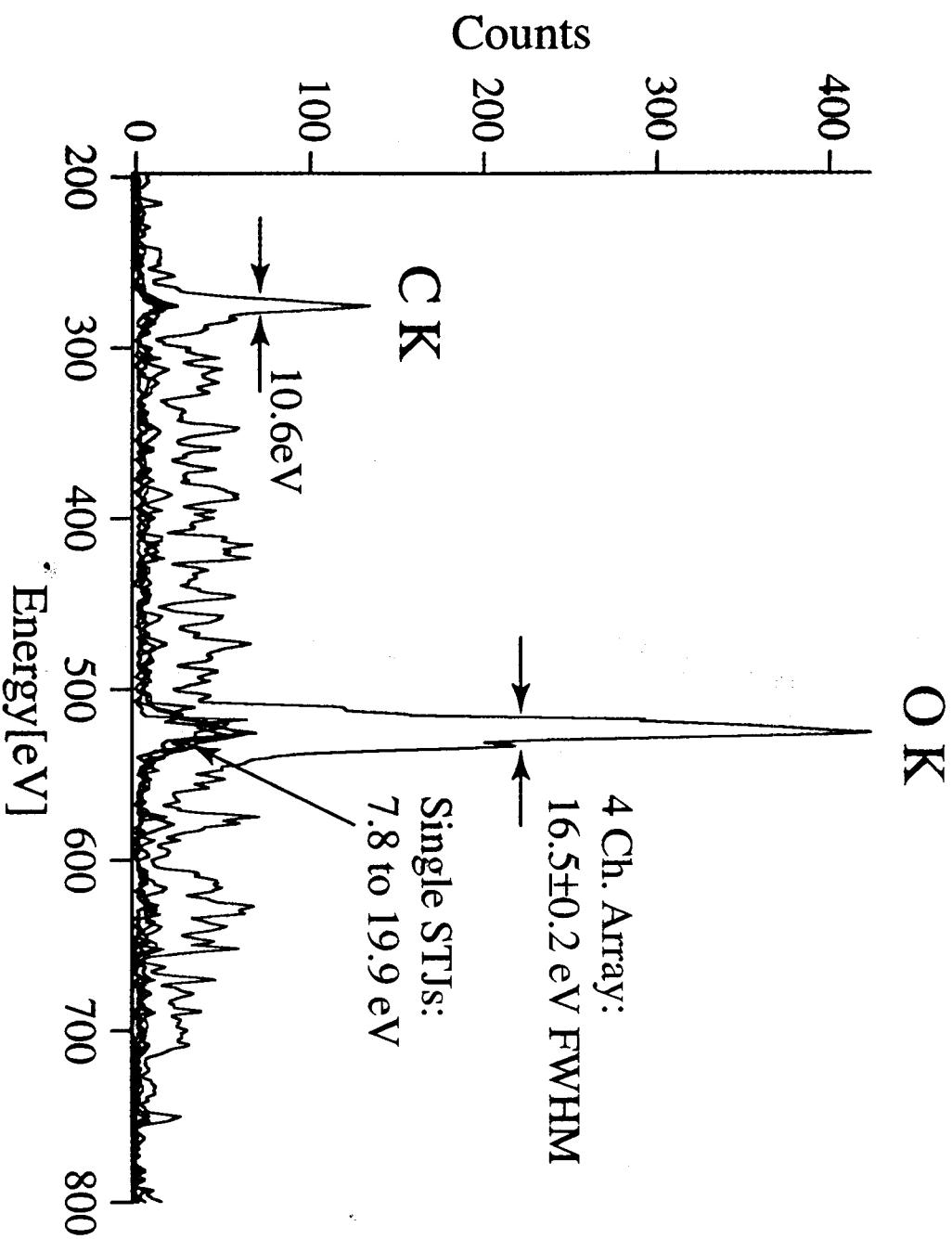


- Similar spectral response
- Crosstalk < 0.1%

# Future Work: Larger Arrays



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- Larger Arrays
- Digital Signal Pr.
- Ta-based STJs

- SR-XRF
  - Biophysics
  - Material Science
- TXRF

# Summary

Superconducting Tunnel Junction (STJ) detectors:

- 1.7 to 8.9 eV FWHM from 50 eV to 1 keV
- Count rates up to  $\approx$ 10,000 counts/s
- High efficiency < 1keV, less at higher E  $\Rightarrow$  Pb
- STJ areas  $\approx$ 100  $\mu\text{m}$  x 100  $\mu\text{m}$   $\Rightarrow$  Arrays

Two-stage ADR cryostat with snout:

- Easy operation, no pumping on He bath
- 80 mK base T; 20 h hold time below 400 mK
- Operation in  $p \approx 2 \cdot 10^{-9}$  Torr without baking

X-ray fluorescence measurements:

- Dilute samples, soft x-ray XAS